OPEN-FILE REPORT 2000-013

SEISMIC HAZARD EVALUATION OF THE EL TORO 7.5-MINUTE QUADRANGLE, ORANGE COUNTY, CALIFORNIA

2000

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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PREFACE

With the increasing public concern about the potential for destructive earthquakes in northern and southern California, the State Legislature passed the Seismic Hazards Mapping Act in 1990. The purpose of the Act is to protect the public from the effects of strong ground shaking, liquefaction, landslides or other ground failure, and other hazards caused by earthquakes. The program and actions mandated by the Seismic Hazards Mapping Act closely resemble those of the Alquist-Priolo Earthquake Fault Zoning Act (which addresses only surface fault-rupture hazards) and are outlined below:

1. **The State Geologist** is required to delineate the various "seismic hazard zones."

2. **Cities and Counties**, or other local permitting authorities, must regulate certain development "projects" within the zones. They must withhold the development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans.

3. **The State Mining and Geology Board (SMGB)** provides additional regulations, policies, and criteria to guide cities and counties in their implementation of the law. The SMGB also provides criteria for preparation of the Seismic Hazard Zone Maps (Web site http://www.consrv.ca.gov/dmg/shezp/zoneguid/) and for evaluating and mitigating seismic hazards.

4. **Sellers (and their agents)** of real property within a mapped hazard zone must disclose at the time of sale that the property lies within such a zone.

As stated above, the Act directs the State Geologist, through the Division of Mines and Geology (DMG) to delineate seismic hazard zones. Delineation of seismic hazard zones is conducted under criteria established by the Seismic Hazards Mapping Act Advisory Committee and its Working Groups and adopted by the California SMGB.

The Official Seismic Hazard Zone Maps, released by DMG, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available from:

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
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Seismic Hazard Evaluation Reports, released as Open-File Reports (OFR), summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These Open-File Reports are available for reference at DMG offices in Sacramento, San Francisco, and Los Angeles. Copies of the reports may be purchased at the Sacramento, Los Angeles, and San Francisco offices. In addition, the Sacramento office offers prepaid mail order sales for all DMG OFRs. **NOTE: The Open-File Reports are not available through BPS Reprographic Services.**

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Seismic Hazard Evaluation Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that the 1) process for zoning liquefaction hazards remain unchanged and that 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Evaluation Report summarizes the development of the hazard zone map for each area. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historic high-water-table information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the El Toro 7.5-minute Quadrangle (scale 1:24,000).

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the El Toro 7.5-Minute Quadrangle, Orange County, California

By
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California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the El Toro 7.5-minute Quadrangle (scale 1:24,000). This section and Section 2 addressing earthquake-induced landslides, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazards zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Liquefaction-induced ground failure has historically been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated granular sediments within the upper 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the El Toro Quadrangle.

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils is generally confined to areas covered by Quaternary sedimentary deposits. Such areas consist mainly of alluviated valleys, floodplains, and canyon regions. The evaluation is based on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth data, most of which are gathered from a variety of sources. The quality of the data used varies. Although selection of data used in this evaluation was rigorous, the state of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth and thickness of liquefiable sediments, depth to ground water, rate of drainage, slope gradient, proximity to free-face conditions, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to determine the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction potential, opportunity, susceptibility, and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The El Toro Quadrangle covers an area of about 62 square miles along the southwestern edge of the Santa Ana Mountains in eastern Orange County. This includes all or parts of the cities of Irvine, Lake Forest, and Mission Viejo as well as unincorporated areas of the county. Major transportation routes traversing the El Toro Quadrangle include the Santa Ana Freeway (I-5), San Diego Freeway (I-405), Orange County Eastern Transportation Corridor (Route 231), Foothill Transportation Corridor, Portola Parkway, Santiago Canyon Road, and El Toro Road.

The topography of the quadrangle consists of the gently west-sloping Tustin Plain that merges to the east with the foothills of the Santa Ana Mountains that are characterized by southwest-trending canyons, washes, and ridges. Exceptions to this are the northwest-trending Loma Ridge, Limestone Canyon, and Santiago Canyon. Along the southwesternmost edge of the quadrangle is a small portion of the San Joaquin Hills. Elevations within the El Toro Quadrangle range from 200 feet in the southwest to just over 2000 feet near the eastern edge of the study area.

Approximately 70 percent of the quadrangle lies within the San Diego Creek Watershed, a complex system of predominantly southwest-draining canyons and washes that ultimately reach Newport Bay. These include Rattlesnake Canyon, Hicks Canyon, Bee Canyon, Round Canyon, Agua Chinon Wash, Borrego Canyon, Serrano Canyon, San Diego Creek, and several unnamed washes. The southeastern portion of the quadrangle drains to the south and includes Aliso Creek, English Canyon, and Oso Creek. In the northeastern portion of the quadrangle the Santiago Creek drainage system flows to the northwest and includes Modjeska Canyon, Williams Canyon and Silverado Canyon. Limestone Canyon joins Santiago Canyon just to the north of the quadrangle. Large bodies of water within the El Toro Quadrangle include Rattlesnake Reservoir, Siphon Reservoir, Lambert Reservoir, Mission Viejo Lake, and Oso Dam.

Significant residential and commercial development has taken place over the past twenty years on the Tustin Plain and upon the slopes and ridges of the foothills. Although most of the residential development involves minor lot grading, some of the larger projects in the upland areas have required substantial grading and drainage modification. The recent closure of the El Toro Marine Corps Air Station has opened up a large tract of land for redevelopment. The active Frank R. Bowerman Landfill is located in Bee Canyon.

GEOLOGIC CONDITIONS

Surface Geology

The generalized Quaternary geology of the El Toro Quadrangle is shown in Plate 1.1. The main sources for this map include geologic maps by Tan and others (1984) and Fife

(1974) which were both originally produced at a scale of 1:12000 for use in assessing engineering geologic conditions. These maps were digitized and compiled with new mapping by the U.S. Geological Survey (Morton, 1999). Map unit nomenclature follows the format developed by the Southern California Areal Mapping Project [SCAMP] (Morton and Kennedy, 1989) and is presented in Table 1.1.

The mapping is based on stratigraphic, geomorphic, and pedologic criteria, namely relative stratigraphic position, environment of deposition, relative degree of erosion, soil type and development, as well as texture (grain size). This geologic map was used in evaluating liquefaction susceptibility of Quaternary sedimentary deposits of the El Toro Quadrangle. The bedrock exposed in this portion of the Santa Ana Mountains is chiefly composed of sandstone, shale and conglomerate and is discussed in detail in Section 2 of this report.

The map shows that approximately 35% of the study area is covered by alluvial sediments of Quaternary age. These deposits have been divided into several subunits that reflect dominant grain size and depositional environment (Table 1.1). Quaternary deposits of older alluvium flank the lower slopes of the foothills and occur upon dissected terraces in canyons. The younger alluvium occurs within the canyons and washes and covers most of the Tustin Plain. Colluvium is a ubiquitous surface unit and it is shown on the map in areas where it is significantly developed.

Map Unit	Environment of Deposition	Age
Ql	lacustrine	Holocene
Quc	colluvium/ slopewash	undifferentiated Holocene to late Pleistocene
Qyfa, Qyfac, Qyfsa	alluvial fans	Holocene to late Pleistocene
Qya, Qyaa	axial channel/ valley deposits	Holocene to late Pleistocene
Qvofa, Qvofsa	alluvial fans	middle to early Pleistocene
Qvoaga, Qvoaa	axial channel/ valley deposits	middle to early Pleistocene

Table 1.1. Units of the Southern California Areal Mapping Project (SCAMP) nomenclature used in the El Toro Quadrangle.

Subsurface Geology and Geotechnical Characteristics

Information on subsurface properties was obtained from more than 500 borehole logs in the study area. Sources of subsurface data used for this investigation include borehole logs collected from Leighton and Associates; the California Department of Transportation (Caltrans); the Hazardous Material Management Section of the Orange County Health Care Agency; and the Materials Laboratory of the Orange County Public Facilities & Resources Department. Additional data for this study came from DMG files of seismic reports for hospital and school sites and the database compiled by Sprotte and others (1980) for previous ground response studies.

Lithologic, soil test, and related data from 376 logs were entered into the DMG (Geographic Information System) database. The remaining logs were reviewed during this investigation to aid with the stratigraphic correlation. Locations of all exploratory boreholes in the database for the El Toro Quadrangle are shown in Plate 1.2. Cross sections were constructed from borehole data to correlate soil types and engineering properties, and to extrapolate geotechnical data into outlying areas containing similar soils.

Descriptions of characteristics of geologic units recorded on the borehole logs are given below. These descriptions are necessarily generalized but give the most commonly encountered characteristics of the units (see Table 1.2).

Very old axial channel/alluvial valley deposits (Qvoaa, Qvoaga)

Subsurface data were not extensively collected for this unit. Borehole data show it to consist of alternating beds of reddish-brown, very dense gravel, silty sand, silt and clay.

Very old fan deposits (Qvofa, Qvofsa)

Subsurface data were not extensively collected for this unit. Borehole data show it to predominantly consist of reddish-brown dense to very dense silty sand interbedded with silt and clay.

Young axial channel/alluvial valley deposits (Qya, Qyaa)

Borehole logs for this unit indicate it is predominantly composed of gray gravel, sand, and silt. Compactness of sand layers ranges from loose to medium dense as indicated by both lithologic descriptions and penetration tests performed during drilling.

Young alluvial fan deposits (Qyfa, Qyfac, Qyfsa)

Borehole logs for this unit indicate it is predominantly composed of sand, sandy silt, and silt and clay mixtures. Compactness of sand layers ranges from loose to medium dense as indicated by both lithologic descriptions and penetration tests performed during drilling.

Lacustrine deposits (Ql)

These deposits occur in lakes and reservoirs and behind flood control structures. No effort was made to collect subsurface information for these units. They generally consist of soft, wet, silt to silty sand deposits.

Colluvial deposits (Quc)

Colluvium, also known as slope wash, occurs in small drainages, upstream portions of major drainages and bottom portions of slopes. It interfingers and is gradational with other alluvial units. Borehole logs within the colluvium indicate it consists of loose gravel, sand, silt and clay. Its composition is highly variable and dependent on adjacent bedrock sources.

Artificial fill (Qaf)

These deposits consist of fill resulting from construction and grading activities. No subsurface data were collected for these units.

Geologic Map Unit	Sediment Type	Environment of Deposition	Consistency	Susceptible to Liquefaction?*
Quc	gravel, sand, silt, clay	colluvium/ slopewash	loose	yes
Ql	silty sand, silt	lacustrine	loose	yes
Qyfa, Qyfac, Qyfsa	sand, sandy silt, silt, clay	alluvial fan	loose to medium dense	yes
Qya, Qyaa	gravel, sand, silt	axial channel/ valley deposits	loose to medium dense	yes
Qvofa, Qvofsa	silty sand, silt, clay	alluvial fan	dense to very dense	no
Qvoaa, Qvoaga	gravel, silty sand, silt, clay	axial channel/ valley deposits	very dense	no

* When saturated.

Table 1. 2.   General geotechnical characteristics and liquefaction susceptibility of Quaternary sedimentary units.

GROUND-WATER CONDITIONS

Saturated conditions reduce the normal effective stress acting on loose, near-surface sandy deposits, thereby increasing the likelihood of liquefaction (Youd, 1973). Liquefaction hazard mapping focuses on areas historically characterized by ground-water depths of 40 feet or less. Accordingly, ground-water conditions were investigated in the El Toro Quadrangle to evaluate the depth to saturated sediments. Ground-water depth data were obtained from Singer (1973), geotechnical boreholes, and water-well logs. The depths to first-encountered water, free of piezometric influences, were plotted onto a map of the project area.

Due to limited records of historical high water for the El Toro Quadrangle canyon areas, ground water was assumed to be 10 to 15 feet higher than the measured ground-water values to take into account the potential for seasonal rises in ground-water level. This is considered a reasonable assumption for severe wet-weather conditions. In the alluvial fan areas that open onto the Tustin Plain, the measured ground-water values were not adjusted because of the coarse-grained and unconfined nature of the alluvium. The assumed historical high ground-water levels used for this evaluation are shown on Plate 1.2.

The young alluvial fan deposits that comprise the Tustin Plain consist mainly of sand, gravel, and silt. Generally, the coarser-grained sediments were deposited near mouths of the canyons and washes. Within the El Toro Quadrangle these upper fan areas are interpreted to be intake areas for the recharge of deeper aquifers beneath the Tustin Plain. Because of the coarse-grained nature of these materials, shallow perched water was not encountered nor anticipated within these areas.

PART II

EVALUATING LIQUEFACTION POTENTIAL

Liquefaction occurs in water-saturated sediments during moderate to great earthquakes. Liquefied sediments are characterized by a loss of strength and may fail, causing damage to buildings, bridges, and other such structures. A number of methods for mapping liquefaction hazard have been proposed; Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of susceptibility units, and introduced the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce liquefaction potential. Liquefaction susceptibility is a function of the capacity of sediments to resist liquefaction and liquefaction opportunity is a function of the seismic ground shaking intensity. The application of the Seed Simplified Procedure (Seed and Idriss, 1971) for evaluating liquefaction potential allows a quantitative characterization of susceptibility of geologic units. Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for mapping liquefaction hazards in the Los Angeles region. The method applied in this study for evaluating liquefaction potential is similar to Tinsley and others (1985), combining geotechnical data analyses, and geologic and hydrologic mapping, but follows criteria adopted by the California State Mining and Geology Board (in press).

LIQUEFACTION OPPORTUNITY

According to the criteria adopted by the California State Mining and Geology Board (in press), liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for ground shaking strong enough to generate liquefaction. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period. The earthquake magnitude is the magnitude that contributes most to the acceleration.

For the El Toro Quadrangle, a peak acceleration of 0.29 g to 0.38 g resulting from an earthquake of magnitude 6.8 to 6.9 was used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996) and Cramer and Petersen (1996), respectively. See the ground motion portion (Section 3) of this report for further details.

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of soils to loss of strength when subjected to ground shaking. Primarily, physical properties and conditions of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance. These properties and conditions are correlated with geologic age and environment of deposition. With increasing age of a deposit, relative density may increase through cementation of the particles or the increase in thickness of the overburden sediments. Grain size characteristics of a soil also influence susceptibility to liquefaction. Sands are more susceptible than silts or gravels, although silts of low plasticity are treated as liquefiable in this investigation. Cohesive soils are generally not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in lower liquefaction susceptibility generally result in higher penetration resistances to the soil sampler. Different blow count corrections are used for silty sand and nonplastic silt than for clean sand (Seed and others, 1985). Therefore, blow count or cone penetrometer values are a useful indicator of liquefaction susceptibility.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (more likely to liquefy). Soils that lack resistance (susceptible soils) are typically saturated, loose sandy sediments. Soils resistant to liquefaction include all soil types that are dry or sufficiently dense.

DMG's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps, cross-sections, geotechnical test data, geomorphology, and ground water hydrology. Soil property and soil condition factors such as type, age texture, color, and consistency, along with historic depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, findings can be related in terms of the map units. DMG's qualitative susceptible soil inventory is summarized on Table 1.2.

Older alluvium (Qvofa, Qvofsa, Qvoaa, Qvoaga)

Most of the older Quaternary sedimentary deposits of the El Toro Quadrangle are described in borehole logs as being dense to very dense sand, silt, and clay. In general, these deposits are considered to have a low liquefaction susceptibility.

Younger alluvium (Qya, Qyaa, Qyfa, Qyfsa, Qyfac)

Younger alluvial deposits within the El Toro Quadrangle consist largely of sand, silt, and gravel, and lesser occurrences of clay. Most test boreholes drilled in these units report the presence of loose to medium dense sand and silt. Some deposits consist of very loose sand. Where anticipated ground-water levels are within 40 feet of the surface, these deposits are judged to be susceptible to liquefaction.

Colluvium (Quc)

Colluvial deposits within the El Toro Quadrangle consist of gravel, sand, silt and clay. The composition of this unit is highly variable and dependent on adjacent bedrock sources. Borehole logs indicate that it is typically loose and interfingers with the other alluvial units. Where anticipated ground-water levels are within 40 feet of the surface, these deposits are judged to be susceptible to liquefaction.

Lacustrine Deposits (Ql)

Lacustrine deposits (Ql) within the El Toro Quadrangle occur in lakes and reservoirs and behind other flood-control structures. These units were not included in the hazard zone evaluation and no effort was made to collect subsurface information for them. In general, they consist of soft, wet, silt to silty sand deposits. Liquefaction susceptibility of this unit is high.

Artificial fill (af)

In the El Toro Quadrangle artificial fill consists of engineered fill associated with reservoirs, embankment dams, and freeways. Artificial fill sites are considered to be properly engineered, therefore the liquefaction susceptibility in such areas depends on soil and anticipated ground-water conditions in underlying strata.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and others, 1985; National Research Council, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). This procedure calculates soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR) based on standard penetration test (SPT) results, ground water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The factor of safety (FS) relative to liquefaction is: FS=CRR/CSR. FS, therefore, is a quantitative measure of liquefaction potential. DMG uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site related structures. For a regional assessment DMG normally has a range of FS that results from the liquefaction analyses. The DMG liquefaction analysis program calculates an FS at each sample that has blow counts. The lowest FS in each borehole is used for that location. These FS vary in reliability according to the quality of the geotechnical data. These FS as well as other considerations such as slope, free face conditions, and thickness and depth of potentially liquefiable soil are evaluated in order to construct liquefaction potential maps, which then directly translate to Zones of Required Investigation**.**

Of the 376 geotechnical borehole logs used in this study (Plate 1.2), 248 include blow-count data from SPT's or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2 1/2-inch inside diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (soil density, moisture content, sieve analysis, etc) required for an ideal Seed Simplified Analysis. For boreholes having acceptable penetration tests, liquefaction analysis is performed using logged density, moisture, and sieve test values or using average test values of similar materials.

LIQUEFACTION ZONES

Criteria for Zoning

The areas underlain by late Quaternary geologic units were included in liquefaction zones using the criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (in press). Under those criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historic earthquakes.

2. All areas of uncompacted fills containing liquefaction susceptible material that are saturated, nearly saturated, or may be expected to become saturated.

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable.

4. Areas where existing geotechnical data are insufficient**.**

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historic high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (between 11,000 years and 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historic high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria for liquefaction zoning in the El Toro Quadrangle is summarized below.

Areas of Past Liquefaction

In the El Toro Quadrangle, no areas of documented historic liquefaction are known. Areas showing evidence of paleoseismic liquefaction have not been reported.

Artificial Fills

In the El Toro Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for reservoirs, embankment dams, and freeways. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that included penetration test data and reasonably sufficient lithologic descriptions were used to determine the liquefaction potential. Accordingly, these areas are zoned or not zoned according to the liquefaction potential based on adequate existing geotechnical data. In the younger alluvium, most of the boreholes whose log data were analyzed using the Seed Simplified Procedure contain sediment layers that liquefy under the given earthquake parameters. These areas containing potentially liquefiable material are zoned.

Areas with Insufficient Existing Geotechnical Data

Younger alluvium deposited in stream channel areas generally lack adequate geotechnical borehole information. The soil characteristics and ground-water conditions in these deposits are assumed to be similar to deposits where subsurface information is available.

The stream channel deposits, therefore, are included in the liquefaction zone for reasons presented in criteria item 4a above.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the El Toro 7.5-Minute Quadrangle, Orange County, California

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in El Toro 7.5-minute Quadrangle (scale 1:24,000). This section and Section 1 addressing liquefaction, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Landslides triggered by earthquakes have historically been a major cause of earthquake damage. Landslides triggered by the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes were responsible for destroying or damaging numerous homes and other structures, blocking major transportation corridors, and damaging various types of life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, in loose soils, and on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, most notably in hilly areas already developed or currently undergoing development. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region, which includes the El Toro Quadrangle.

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered primarily from a variety of outside sources; thus the quality of the data is variable. Although the selection of data used in this evaluation was rigorous, the State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Earthquake-generated ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. No attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the El Toro Quadrangle, for more information on the delineation of liquefaction zones.

Information developed in the study is presented in two parts: physiographic, and geologic conditions in PART I, and ground shaking opportunity, landslide hazard potential and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The El Toro Quadrangle covers an area of about 62 square miles along the southwestern edge of the Santa Ana Mountains in eastern Orange County. This includes all or parts of the cities of Irvine, Lake Forest, and Mission Viejo as well as unincorporated areas of the county. Major transportation routes traversing the El Toro Quadrangle include the Santa Ana Freeway (I-5), San Diego Freeway (I-405), Orange County Eastern Transportation Corridor (Route 231), Foothill Transportation Corridor, Portola Parkway, Santiago Canyon Road, and El Toro Road.

The topography of the quadrangle consists of the gently west-sloping Tustin Plain that merges with the southwest-trending canyons, washes, and ridges of the foothills of the Santa Ana Mountains. Exceptions to this are the northwest-trending Loma Ridge, Limestone Canyon, and Santiago Canyon. Along the southwesternmost edge of the quadrangle is a small portion of the San Joaquin Hills. Elevations within the El Toro Quadrangle range from 200 feet in the southwest to just over 2000 feet near the eastern edge of the study area.

Approximately 70 percent of the quadrangle lies within the San Diego Creek watershed, a complex system of predominantly southwest-draining canyons and washes that ultimately reach Newport Bay. These include Rattlesnake Canyon, Hicks Canyon, Bee Canyon, Round Canyon, Agua Chinon Wash, Borrego Canyon, Serrano Canyon, San Diego Creek, and several unnamed washes. The southeast portions of the quadrangle drains to the south and includes Aliso Creek, English Canyon, and Oso Creek. In the northeastern portion of the quadrangle the Santiago Creek drainage system flows to the northwest and includes Modjeska Canyon, Williams Canyon and Silverado Canyon. Limestone Canyon joins Santiago Canyon just to the north of the quadrangle. Large bodies of water within the El Toro Quadrangle include Rattlesnake Reservoir, Siphon Reservoir, Lambert Reservoir, Mission Viejo Lake, and Oso Dam.

Significant residential and commercial development has taken place over the past twenty years within the Tustin Plain and onto the slopes and ridges of the foothills. Although most of the residential development involves minor lot grading, some of the larger projects in the upland areas required substantial grading and drainage modification. The recent closure of the El Toro Marine Corps Air Station has opened a large tract of land for redevelopment. The active Frank R. Bowerman Landfill is located in Bee Canyon.

GEOLOGIC CONDITIONS

Surface and Bedrock Geology

For the El Toro Quadrangle, a geologic map was compiled and digitized by the Southern California Areal Mapping Project [SCAMP] (Morton and Kennedy, 1989) from original mapping by Tan and others (1984) and by Fife (1974). The digital geologic map obtained from SCAMP was modified to reflect the most recent mapping in the area. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of landslides was noted.

The oldest rocks mapped in the El Toro Quadrangle are the Jurassic Bedford Canyon Formation (Jbc) and the Santiago Peak Volcanics (Jsp) which are often referred to as the basement complex or subjacent series. They are exposed in the northeastern corner of the quadrangle and probably supplied much of the source material for the younger formations that overlie them to the west. The Bedford Canyon Formation, which consists of dark argillite, quartzite, meta-sandstone, and conglomerate, is separated by an erosional unconformity from the overlying slightly metamorphosed andesite flows, flow breccia, and volcanic sediments of the latest Late Jurassic (Fife and others, 1967) Santiago Peak Volcanics.

Overlying these rock units, exposed in a moderately west-dipping homocline, is a thick sequence of Upper Cretaceous sedimentary rocks that begins with the Trabuco Formation (Kt). Trabuco Formation is made up of nonmarine reddish fanglomerates that rest directly upon the Jurassic rocks. Kt is exposed along White Canyon. It grades upward into the lower conglomerate layers of the marine Ladd Formation called the Baker Canyon Conglomerate Member (Klb-cg). This conglomerate member is overlain by and interfingers with a coarse sandstone member (Klb-sd) with interbedded shale that ultimately grades into the Holz Shale Member (Klh) of the Ladd Formation. Layers of sandstone (Klh-sc) that locally contain resistant calcareous fossil beds mark the top of the Holz Shale Member. The Williams Formation overlies the Ladd Formation and consists of a lower conglomeratic sandstone, the Schulz Ranch Sandstone Member (Kws), and an upper, fine-grained, shaly sandstone, the Pleasants Sandstone Member (Kwp-f) that in places is sandy and conglomeratic (Kwp-sc). The uppermost layers of the Pleasants Sandstone Member mark the top of the marine Upper Cretaceous sedimentary rocks.

The oldest Tertiary unit in the area is the Paleocene Silverado Formation (Tsi). It is characterized by an unsorted basal conglomerate (Tsi-sc) that continues upward into arkosic, micaceous sandstone layers and two persistent and distinctive clay beds named the Claymont Clay Bed and Serrano Clay Bed. The Serrano Clay Bed is a white sandy clay that was mined for its kaolinite clay beginning in the 1920's. The top of this bed is chosen, where it is exposed, as the boundary between the Silverado Formation and the overlying Eocene Santiago Formation (Tsa). Elsewhere, the Santiago Formation contact has been mapped at the beginning of a repetitious series of massive sandstone beds, which are separated by greenish gray shaly siltstone beds.

In the El Toro Quadrangle, the Sespe Formation (Ts) of late Eocene to early Miocene age and the Vaqueros Formation (Tv) of early Miocene age are typically interbedded. However, the lower sequence consisting mainly of nonmarine sedimentary rocks is generally attributed to the Sespe Formation and the upper sequence, consisting mostly of marine sedimentary rocks, to the Vaqueros Formation. The combined Vaqueros and Sespe formations (Tvs) are the most widespread among the bedrock units in the quadrangle. The Vaqueros Formation is conformable and transitional with the overlying Miocene Topanga Formation (Tt), which, in turn, is conformably overlain by the Puente Formation that consists of two members, the La Vida Member (Tpl) and Soquel Member (Tps). The La Vida Member of the Puente Formation and the Monterey Formation (Tm) both have a similar stratigraphic position and are composed of siltstone, thin-bedded sandstone and calcareous beds. The Monterey Formation also contains diatomaceous and siliceous shale and siltstone beds. The Soquel Member consists of sandstone (Tps-sc), interbedded siltstone (Tpst), and local conglomerate (Tps-cg) and conformably overlies the La Vida Member. In many areas, the two members have gradational contacts.

The late Miocene to early Pliocene Oso Member (Tco) of the Capistrano Formation (Tc) is characterized by massive white sandstone and generally has a sharp boundary with the underlying Soquel Member of the Puente Formation. The Niguel Formation (Tn) of late Pliocene age is only found in the southern part of the area where it overlies the Monterey Formation and Capistrano Formation. It is composed mainly of conglomerate and sandstone.

Approximately one third of the quadrangle is covered by alluvial deposits of Quaternary age. Younger alluvial deposits (Qyfa, Qyfac, Qyfsa, Qya, Qyaa) occur within the canyons and washes and cover most of the Tustin Plain. Colluvium/slopewash (Quc) generally occupies the upstream sections of canyons and the bases of slopes. Modern lacustrine sediments (Ql) are accumulating in several reservoirs and behind flood-control structures. Older alluvial sediments (Qvofa, Qvofsa, Qvoaga, Qvoaa) flank the lower slopes of foothills and occur upon dissected terraces along the sides of canyons. A more detailed discussion of the Quaternary deposits in the El Toro Quadrangle can be found in Section 1.

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, they first must be ranked based on their overall shear strength. Generally, the primary source for rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear strength data for the rock units identified on the geologic map were obtained from the cities of Lake Forest and Mission Viejo (see Appendix A). The locations of rock and soil samples taken for shear testing are shown on Plate 2.1.

Shear strength data gathered from the above sources were compiled for each mapped geologic unit, and subdivided for fine-grained and coarse-grained lithologies if appropriate. Geologic units were grouped on the basis of average angle of internal friction (average ϕ) and lithologic character. When available, shear tests from adjacent quadrangles were used to augment data for geologic formations that had little or no shear test information. For the El Toro Quadrangle, a large number of shear test values were obtained from the adjacent Black Star Canyon Quadrangle (Appendix A), related to the construction of the Highway 241 Corridor.

To subdivide mapped geologic formations that have both fine-grained and coarse-grained lithologies, we assumed that where stratigraphic bedding dips into a slope (favorable bedding) the coarse-grained material strength dominates, and where bedding dips out of a slope (adverse bedding) the fine-grained material strength dominates. We then used structural information from the geologic map (see "Structural Geology") and terrain data in the form of slope gradient and aspect, to identify areas with a high potential for containing adverse bedding conditions. These areas, located on the map, were then used to modify the geologic material-strength map to reflect the anticipated lower shear strength for the fine-grained materials.

The results of the grouping of geologic materials for the El Toro Quadrangle are shown in Tables 2.1 and 2.2.

EL TORO QUADRANGLE
SHEAR STRENGTH GROUPS STATISTICS

	Formation Name	Number Tests	Unit Phi Mean/Median (deg)	Group Phi Mean/Median (deg)	Group C Mean/Median (psf)	No data: Similar Lithology	Phi Values: Used in Stability Analyses
Group 1	Klb-cg/Klb-sd	***2***	***38.5/38.5***				
	Klh(fbc)/Klh-sc	***6***	***39/39***				
	Kwp-sc	***6***	***36/33.5***			Jbc,Jsp	
	Kws(fbc)	***2***	***40/40.5***	39/44	727/600	Kt	39
	Tsi-sc	***14***	***36.7/37***			Tsi(fbc)	
	Tvs(fbc)	11	40/44				
Group 2	Qvofa	2	32/32				
	Tc(fbc)	1	30/30			Klh(abc),Kwp(abc)	
	Tco(fbc)	12	33.5/35			Kwp-f,Qvoaa	
	Tps(fbc)	7	34/36	34.7/35	757/410	Qvoaga, Tn	34
	Tsa	***11***	***34.535***			Qvofsa,Tv(fbc)	
	Tt(fbc)	6	36/36			Tps-cg,Tps-sc	
	Tvs(abc)	***54***	***35.6/36***			Ts(fbc), Tsi(abc)	
Group 3	Kws(abc)	***3***	***28/29***				
	Qaf	7	31.2/29				
	Quc	1	30/30			Qya	
	Qyaa	1	28/28			Qyfac,Qyfsa	
	Qyfa	5	2829	28.6/29.5	487/317	Tc(abc)	29
	Tco(abc)	1	31/31			Tpst	
	Tm(fbc)	3	31/33			Ts(abc),Tv(abc)	
	Tpl(fbc)	1	31/31				
	Tps(abc)	2	30/30				
Group 4	Tm(abc)	11	26.7/28	26.2/27.5	611/600	Tt(abc)	25
	Tpl(abc)	7	25.4/23				
Group 5	Qls	2	18/18	18/18	980/980		18

(abc) - adverse bedding condition
(fbc) - favorable bedding condition
italicized phi values are from Black Star Canyon Quadrangle

Table 2.1 Summary of the Shear Strength Statistics for the El Toro Quadrangle.

EL TORO QUADRANGLE SHEAR STRENGTH GROUPS				
Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Jbc,Jsp Klb-cg,Klb-sd Klh(fbc),Klh-sc Kt, Kwp-sc Kws(fbc), Tsi(fbc) Tsi-sc, Tvs(fbc)	Klh(abc),Kwp(abc) Kwp-f,Qvoaa Qvofa Qvoaga,Qvofsa Tc(fbc),Tco(fbc) Tn, Tps(fbc) Tps-cg,Tps-sc Ts(fbc),Tsa Tsi(abc) Tt(fbc),Tv(fbc) Tvs(abc)	Kws(abc),Qaf Quc,Qya Qyaa,Qyfa Qyfac,Qyfsa Tc(abc),Tco(abc) Tm(fbc),Tpl(fbc) Tps(abc),Tpst Ts(abc),Tv(abc)	Tm(abc) Tpl(abc) Tt(abc)	Qls

Table 2.2. Summary of the Shear Strength Groups for the El Toro Quadrangle.

Structural Geology

Accompanying the digital geologic map were digital files of associated geologic structural data, including bedding and foliation attitudes (strike and dip) and fold axes. We used the structural geologic information provided with the digital geologic map (SCAMP) and from Tan and others (1984) and Fife (1974) to categorize areas of common stratigraphic dip direction and magnitude, similar to the method presented by Brabb (1983). The dip direction category was compared to the slope aspect (direction) category and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, and the bedding dip was greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area. This information was then used to subdivide mapped geologic units into areas where fine-grained and coarse-grained strengths would be used.

Landslide Inventory

The evaluation of earthquake-induced landsliding requires an up-to-date and complete picture of the previous occurrence of landsliding. An inventory of existing landslides in the El Toro Quadrangle was prepared by reviewing published maps and reports showing or discussing landslides, such as Tan and others (1984) and Fife (1974), and combining field observations, analysis of aerial photos (see Air Photos in References for a list), and interpretation of landforms on current and older topographic maps. The most landslide-prone bedrock units in the quadrangle are the Sespe, Vaqueros and Puente formations and the Holz Shale Member of the Ladd Formation. The most stable are the Bedford Canyon

Formation and the Santiago Peak Volcanics. Most of the landslides inventoried are debris slides and rock slides.

The landslide inventory map was digitized and information on confidence of interpretation (definite, probable, or questionable) and other properties, such as activity, thickness, and associated geologic unit(s), were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

PART II

EARTHQUAKE-INDUCED LANDSLIDE GROUND SHAKING OPPORTUNITY

Design Strong-Motion Record

The Newmark analysis used in delineating the earthquake-induced landslide zones requires the selection of a design earthquake strong-motion record. For the El Toro Quadrangle, the selection was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996; Cramer and Petersen, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.8
Modal Distance:	8.8 to 26.3 km.
PGA:	0.29g to 0.45 g

The strong-motion record selected was the Channel 3 (north horizontal component) Pacoma-Kagel Canyon Fire Station recording from the magnitude 6.7 January 1994, Northridge earthquake (Shakal and others, 1994). This record had a source to recording site distance of 2.6 km and a PGA of 0.44g. The selected strong-motion record was not scaled or otherwise modified prior to analysis.

Displacement Calculation

To develop a relationship between the yield acceleration (a_y; defined as the horizontal ground acceleration required to cause the factor of safety to equal 1.0) and Newmark displacements, the design strong-motion record was integrated twice for a given a_y to find the corresponding displacement, and the process repeated for a range of a_y (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for any combination of geologic material strength and slope angle, as represented by the yield acceleration. We used displacements of 30, 15 and 5 cm as criteria for rating levels of earthquake shaking damage on the basis of the work of Youd (1980), Wilson and Keefer (1983), and the DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.074, 0.13 and 0.21g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant to the El Toro Quadrangle.

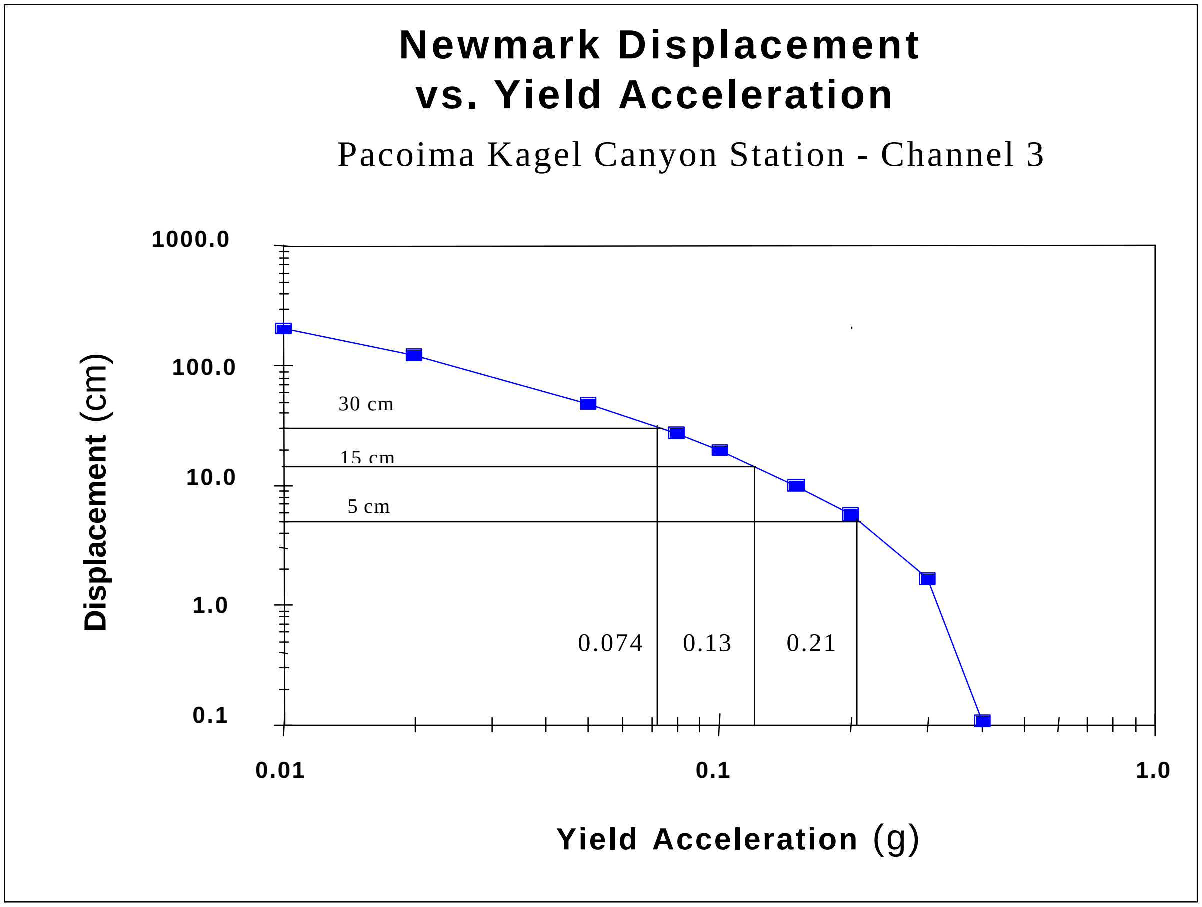

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Pacoima-Kagel Canyon Strong-Motion Record from the January 1994 Northridge, California Earthquake. Record from California Strong Motion Instrumentation Program (CSMIP) Station 24088

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. To calculate slope gradient for the terrain within the El Toro Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1995). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy. Surrounding quadrangle DEMs were merged with the El Toro DEM to avoid the loss of data at the quadrangle edges when the slope calculations were performed. A peak and pit smoothing process was then performed to remove errors in the elevation points.

Areas that have undergone large-scale grading as a part of residential development and recent highway construction in the hilly portions of the El Toro Quadrangle were updated to reflect the new topography. Using 1:40,000-scale NAPP photography taken in 1994 and 1995, photogrammetric DEMs covering the residential graded areas were prepared by the U.S. Bureau of Reclamation with ground control obtained by DMG. Digital files of new topographic contours from the construction of the Eastern and Foothill transportation corridors were obtained from the Silverado Construction Company and used to update topography in those areas. The photogrammetric DEMs and DEMs from the highway contour files were merged into the USGS DEM, replacing the areas of out-dated elevation data. Plate 2.2 shows those areas where the topography is updated to 1994-95 grading conditions.

A slope-gradient map was made from the combined DEMs using a third-order, finite difference, center-weighted algorithm (Horn, 1981). This map was used in conjunction with the geologic strength map in preparation of the earthquake-induced landslide hazard potential map.

Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield acceleration calculated by Newmark's equations represents the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. The acceleration values were compared with the ground shaking opportunity, defined by Figure 2.1, to determine the earthquake-induced landslide hazard potential. Based on the criteria described in Figure 2.1 above, if the calculated yield acceleration was less than 0.074g, expected displacements could be greater than 30 cm, and a HIGH (H on Table 2.3) hazard potential was assigned. Likewise, if the calculated a_y fell between 0.074 and 0.13g a MODERATE (M on Table 2.3) hazard potential was assigned, between 0.13 and 0.21g a LOW (L on Table 2.3) potential was assigned, and if a_y were greater than 0.21g a VERY LOW (VL on Table 2.3) potential was assigned.

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

El Toro Quadrangle
Hazard Potential Matrix

Geologic Strength Group	I 0 to 18 0 to 10	II 19 to 24 11 to 14	III 25 to 33 15 to 18	IV 34 to 43 19 to 23	V 44 to 56 24 to 29	VI 57 to 65 30 to 33	VII 66 to 70 34 to 35	VIII >71 >36
			SLOPE GRADIENT CATEGORY					
1	VL	VL	VL	VL	VL	L	M	H
2	VL	VL	VL	VL	L	M	H	H
3	VL	VL	VL	L	M	H	H	H
4	VL	VL	L	M	H	H	H	H
5	L	M	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the El Toro Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone.

EARTHQUAKE-INDUCED LANDSLIDE ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (1996). Under those criteria, earthquake-induced landslide zones are areas meeting one or both of the following:

1. Areas identified as having experienced landslide movement in the past (including all mappable landslide deposits and source areas), and, where possible, areas known to have experienced earthquake-induced landsliding during historic earthquakes.

2. Areas where geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

Existing Landslides

Studies of the types of landslides caused by earthquakes (Keefer, 1984) show that re-activation of the whole mass of deep-seated landslide deposits is rare. However, it has been observed that the steep scarps and toe areas of existing landslides, which formed as a result of previous landslide movement, are particularly susceptible to earthquake-induced slope failure. In addition, because they have been disrupted during landslide movement, landslide deposits are inferred to be weaker than coherent, undisturbed, adjacent source rocks. Finally, we felt that a long duration, San Andreas fault-type earthquake could be capable of initiating renewed movement in existing deep-seated landslide deposits. Therefore, all existing landslides identified in the inventory with a definite or probable confidence of interpretation were included in the hazard zone.

Geologic and Geotechnical Analysis

On the basis of a DMG pilot study (McCrink and Real, 1996) the earthquake-induced landslide zone includes all areas determined to lie within the High, Moderate and Low levels of hazard potential. Therefore, as shown in Table 2.3, geologic strength group 5 is always included in the zone (mapped landslides); strength group 4 above 24 %; strength group 3 above 33 %; strength group 2 above 43 %; and strength group 1, the strongest rock types, were zoned for slope gradients above 56 %. This results in roughly 22% of the land in the quadrangle lying within the hazard zone.

ACKNOWLEDGMENTS

The authors thank Richard Schlesinger and Irma L. Garcia of the City of Mission Viejo, and Martha Ford, Sue Adams and Christy Dammarell of the City of Lake Forest for their assistance in obtaining geologic material strength data used in the preparation of this report. Patricia V. Kennedy assisted in the collection of geotechnical data. Dean Montgomery, George Knight, and Monte Lorenz of the U.S. Bureau of Reclamation supplied topographic data for areas of mass grading in the quadrangle. Keith Butz of the Silverado Construction Company supplied topographic data for the Eastern and Foothill transportation corridor areas. Technical review of the methodology was provided by Bruce Clark, Randy Jibson, Robert Larson, Scott Lindvall, and J. David Rogers, who are members of the State Mining and Geology Board's Seismic Hazards Mapping Act Advisory Committee Landslides Working Group. At DMG, special thanks to Scott Shepherd, Teri McGuire, and Bob Moskovitz for their Geographic Information System operations support, Barbara Wanish for designing and plotting the graphic displays associated with the hazard zone map and this report and Ellen Sander for the entry of geotechnical data into the Access database.

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AIR PHOTOS

Orange County Planning Department, E.L.Pearsons & Associates/Robert J. Lung & Associates July/August 1970 Aerial Photographs, flight 27, frames 18-22, flight 28, frames 16-22, flight 29, frames 16-26, flight 30, frames 15-29, flight 31, frames 14-27, flight 32, frames 15-27, flight 33, frames 21-29, flight 34, frames 24-28, flight 35, frames 27-29, black and white, vertical, approximate scale 1:14000.

USGS (U.S. Geological Survey), NAPP Aerial Photography, June 1, 1994, flight 6866, frames 90-94, frames 135-139, black and white, vertical, approximate scale 1:40000.

APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Lake Forest	51
City of Mission Viejo	63
Corridor Design Management Group (Black Star Canyon Quadrangle)	216

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the El Toro 7.5-Minute Quadrangle, Orange County, California

By

Mark D. Petersen, Chris H. Cramer, Geoffrey A. Faneros, Charles R. Real, and Michael S. Reichle

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included, are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5- minute quadrangle and portions of the adjacent eight quadrangles.

They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the “Simple Prescribed Parameter Value” method (SPPV) described in the site investigation guidelines (California State Mining and Geology Board, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2, addressing liquefaction and earthquake-induced landslide hazards, constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG’s Internet homepage:
http://www.consrv.ca.gov/dmg/shezp/

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the seismogenic sources as published in the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

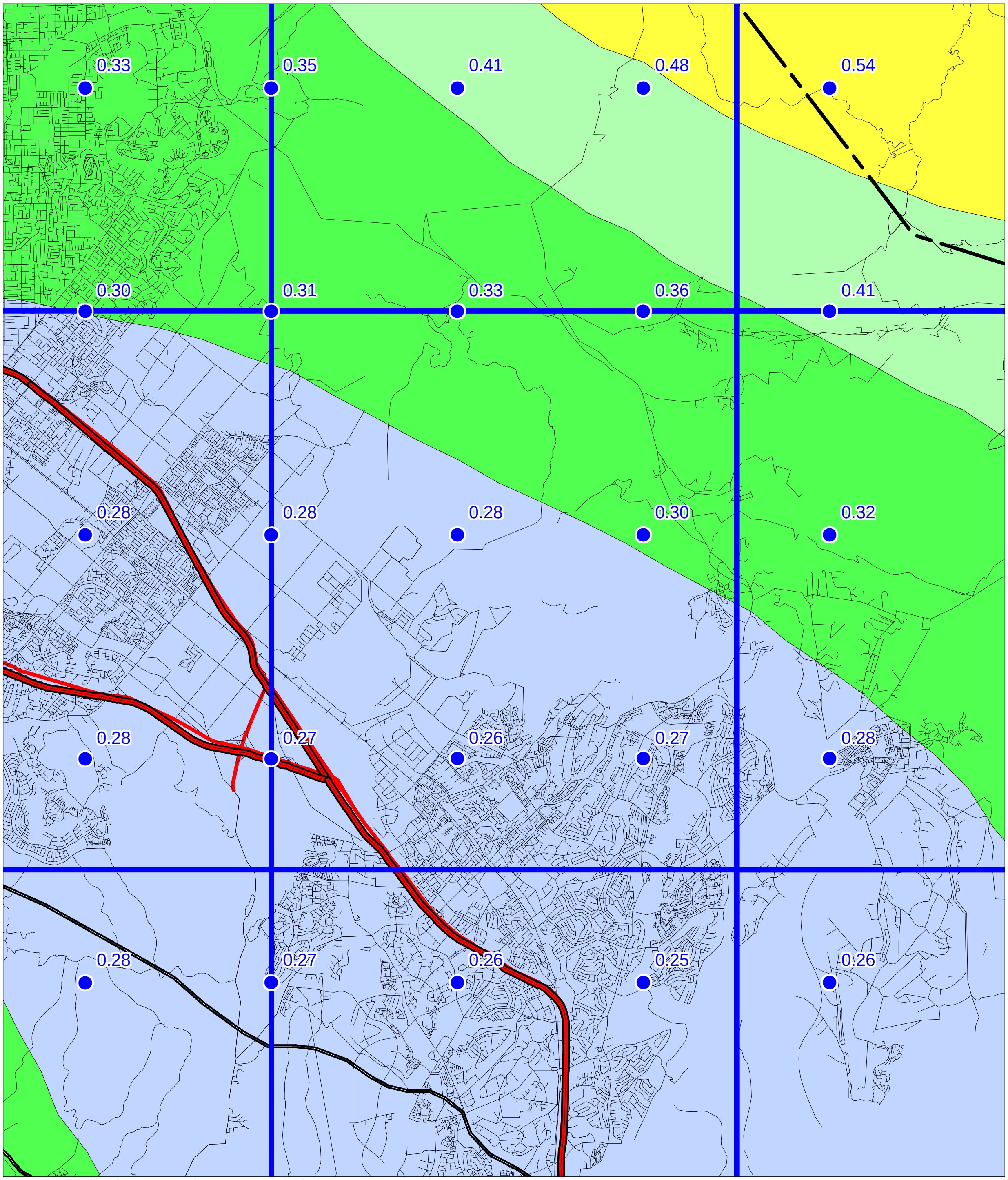
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent

EL TORO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

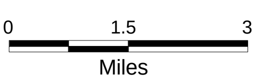


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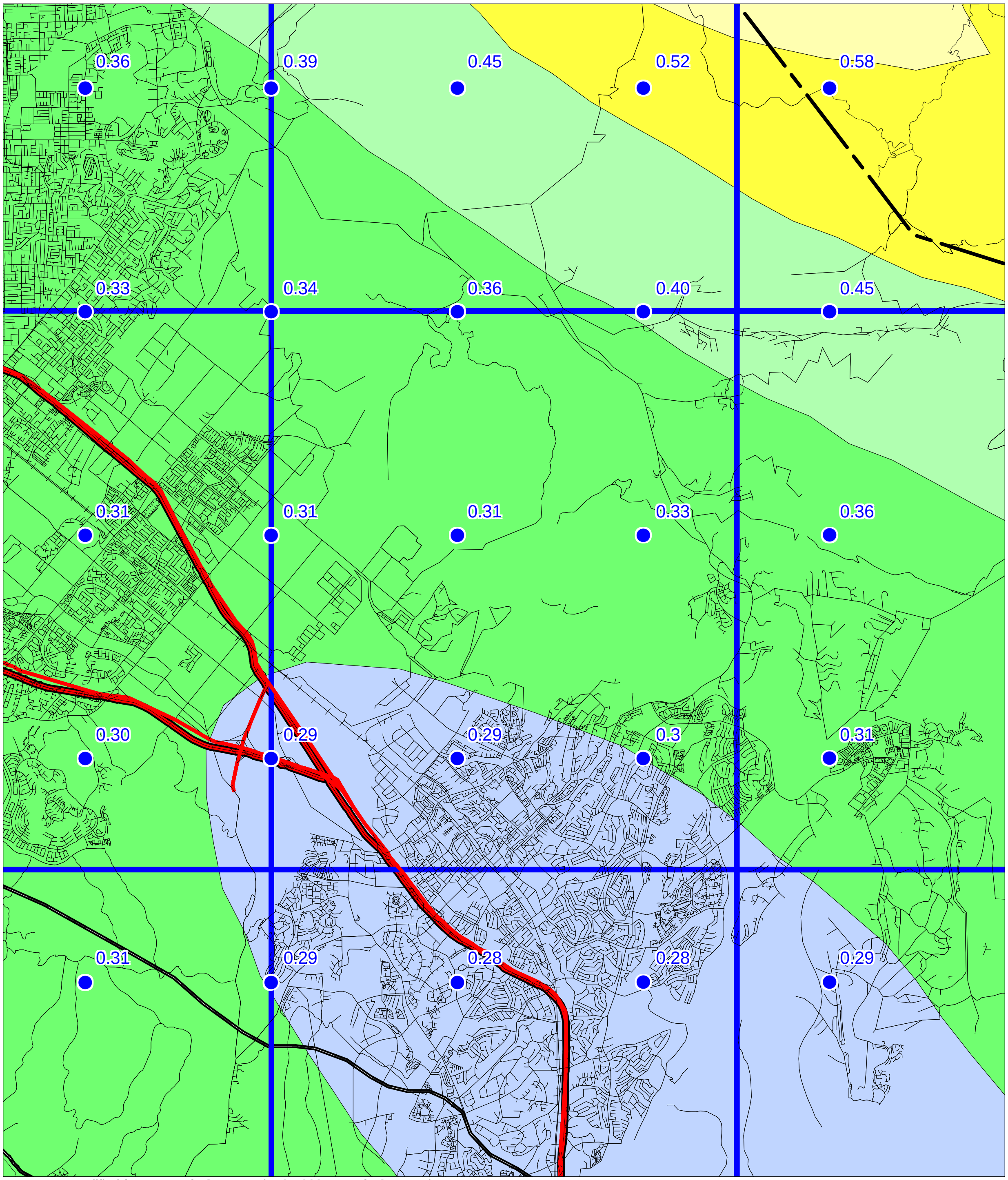
Figure 3.1

EL TORO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

Figure 3.2

EL TORO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS

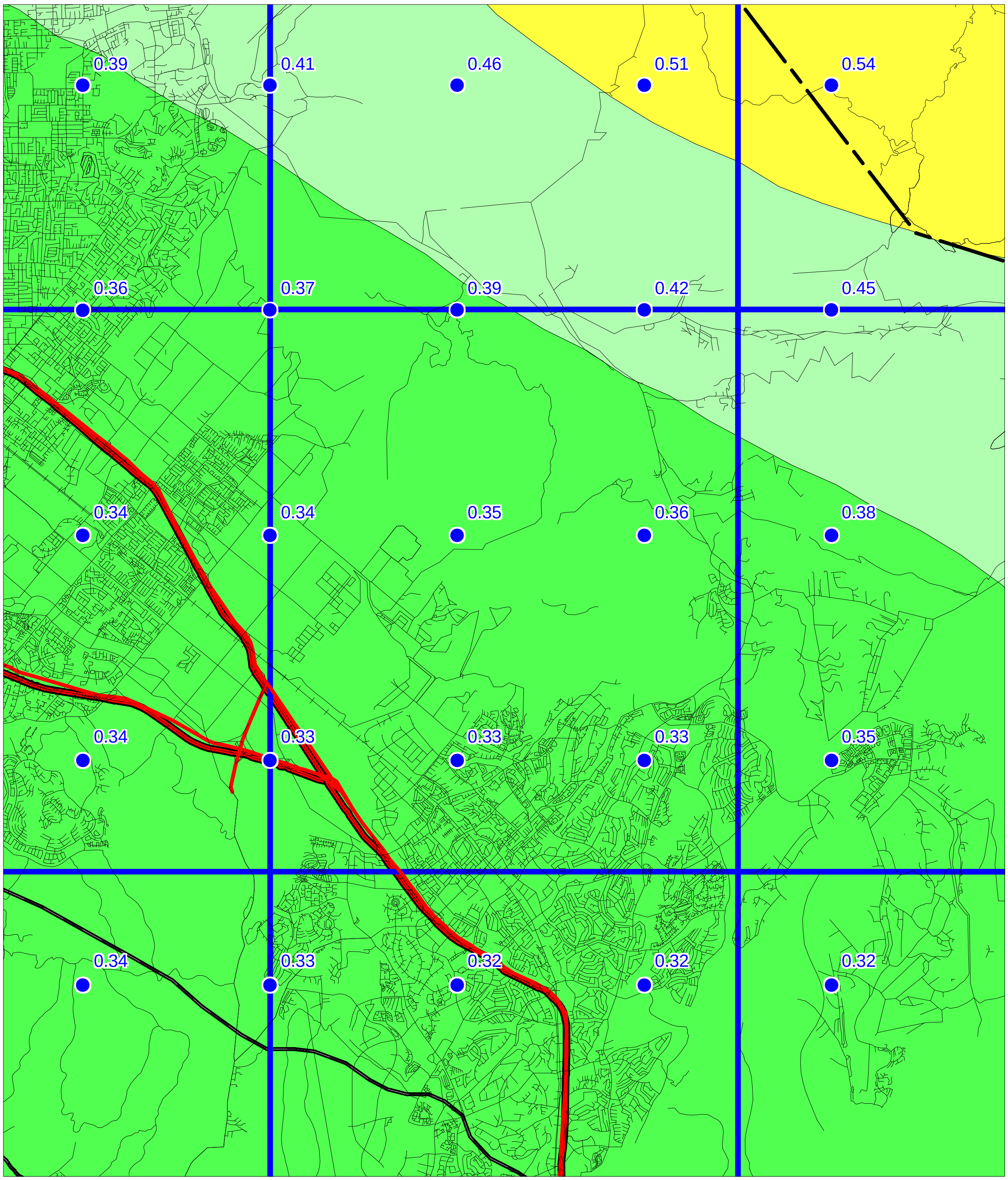


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Figure 3.3

quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

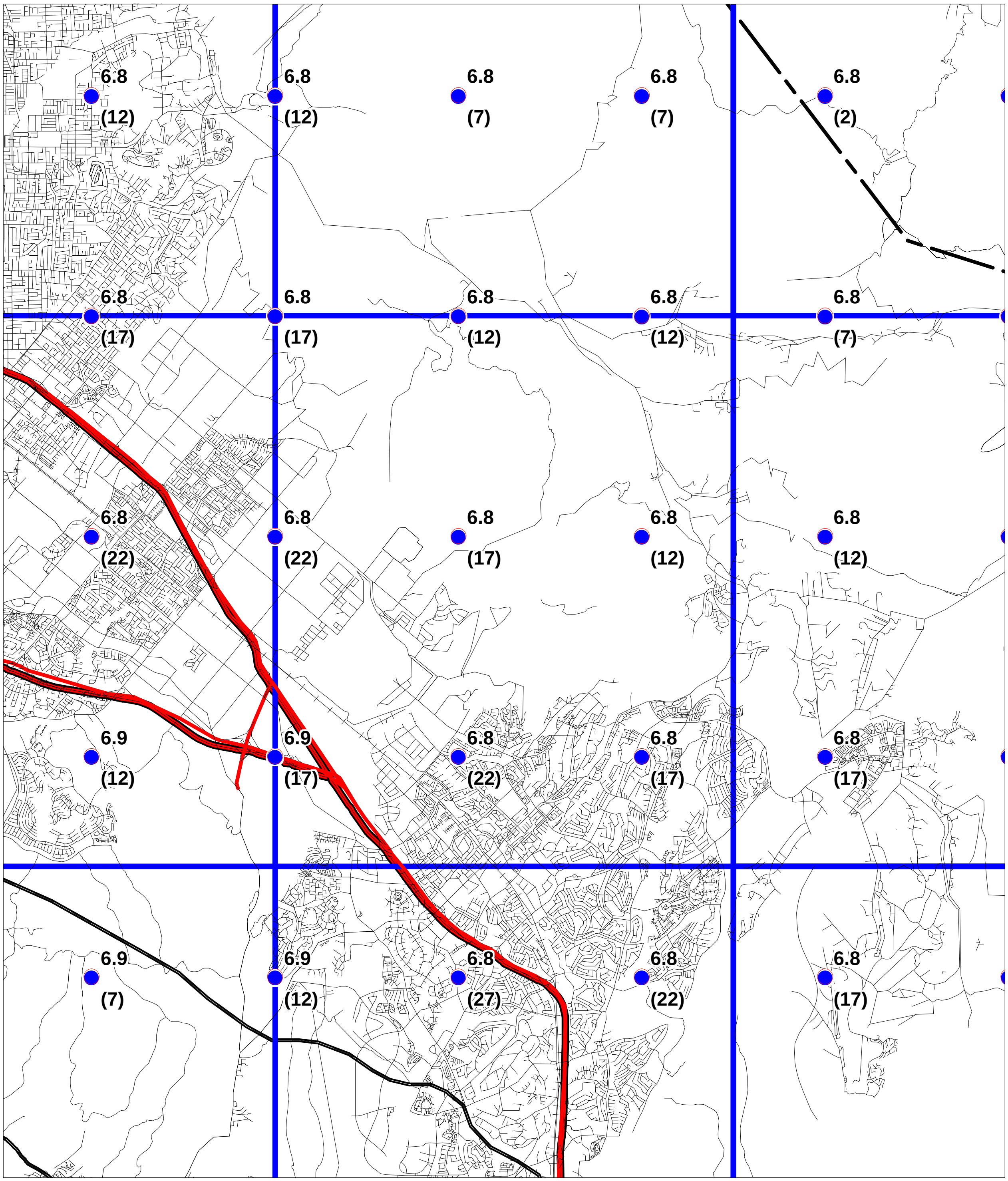
1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation

EL TORO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

Figure 3.4

of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not previously been recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (California State Mining and Geology Board, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

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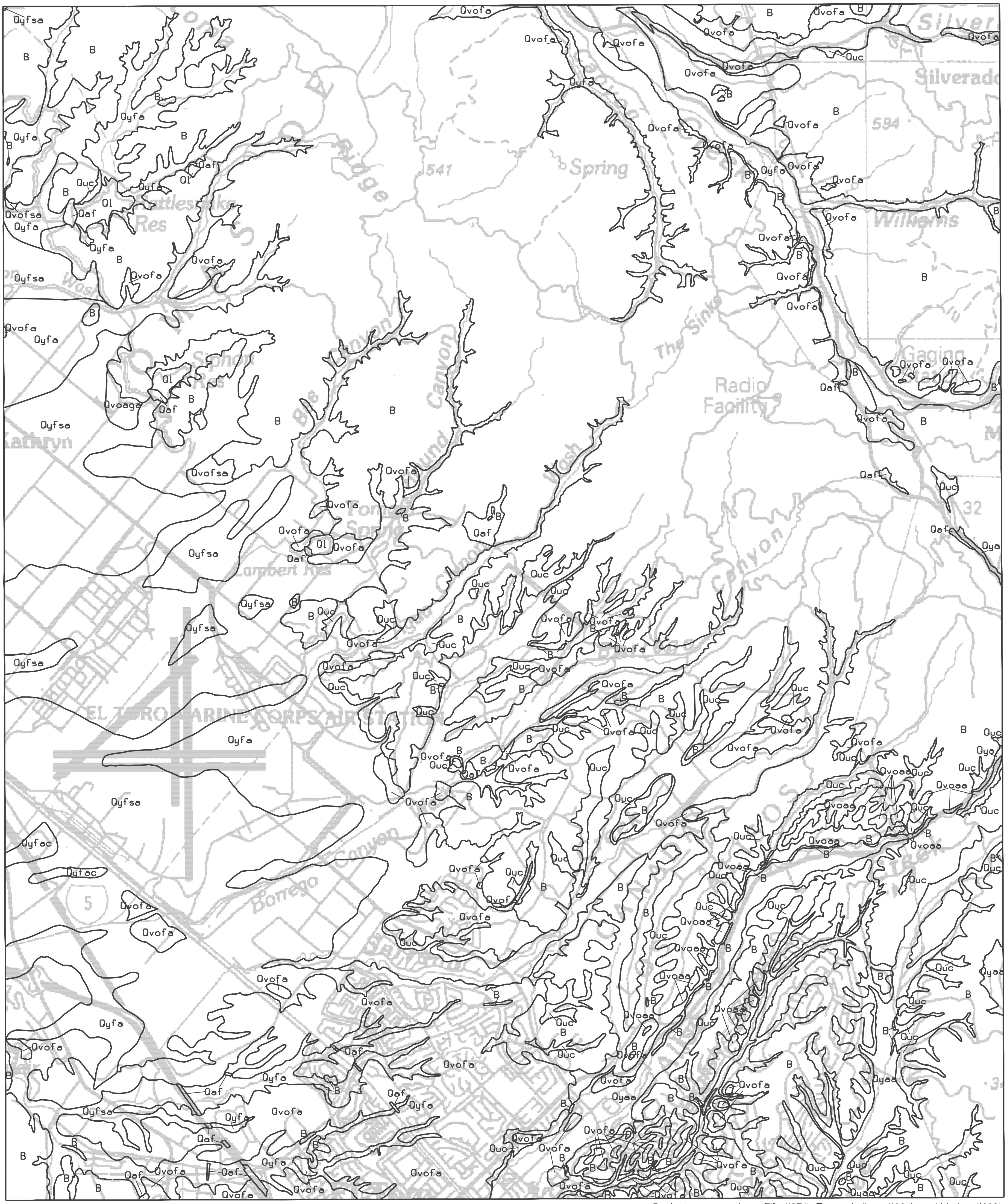


Base map enlarged from U.S.G.S. 30 x 60–minute series

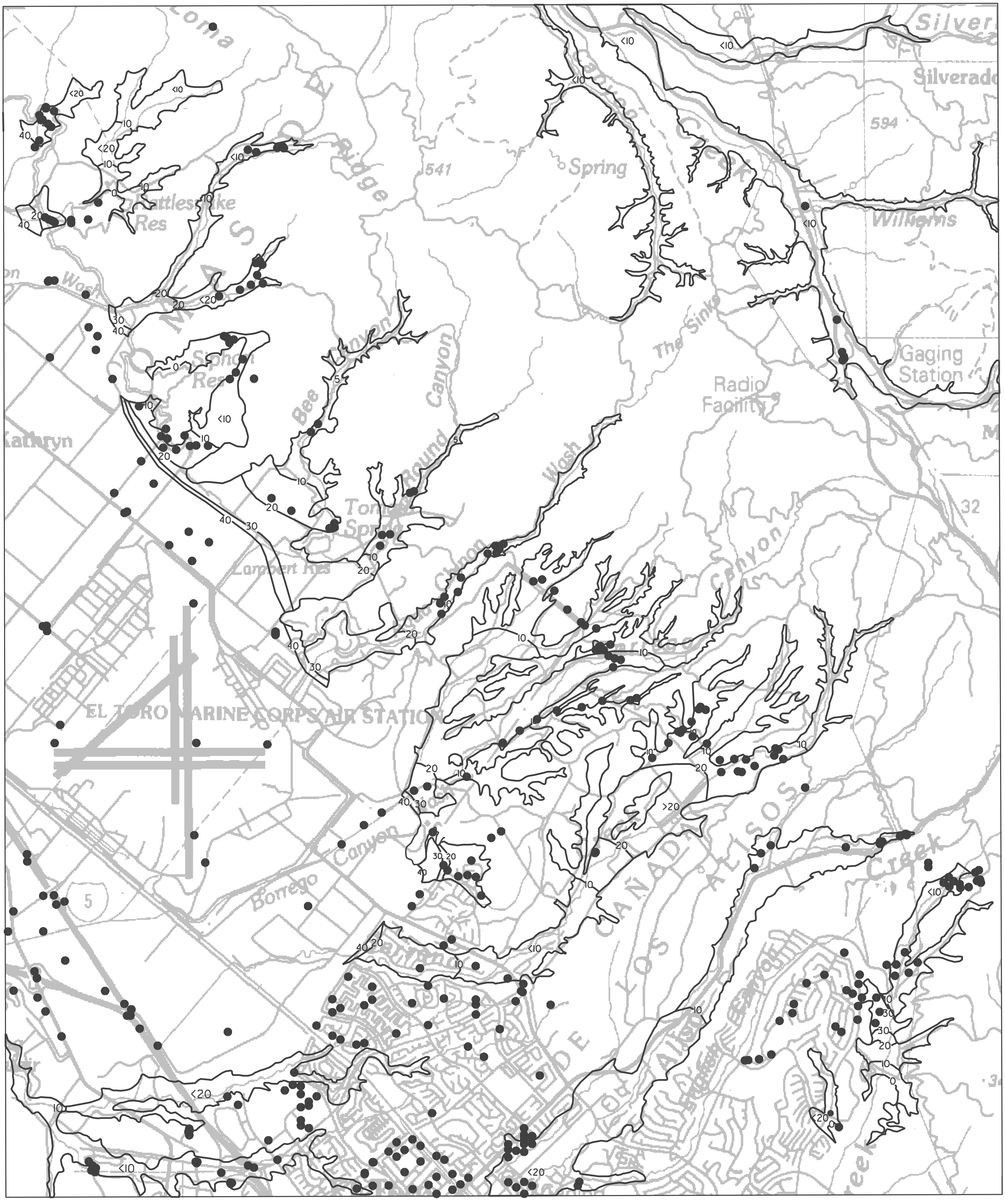
Geologic mapping from Fife (1974), Tan and others (1984), and Morton (1999).

Plate 1.1 Quaternary Geologic Map of the El Toro Quadrangle.
See Geologic Conditions section in report for descriptions of the units.

B = Pre–Quaternary bedrock.

ONE MILE

Scale



Base map enlarged from U.S.G.S. 30 x 60–minute series

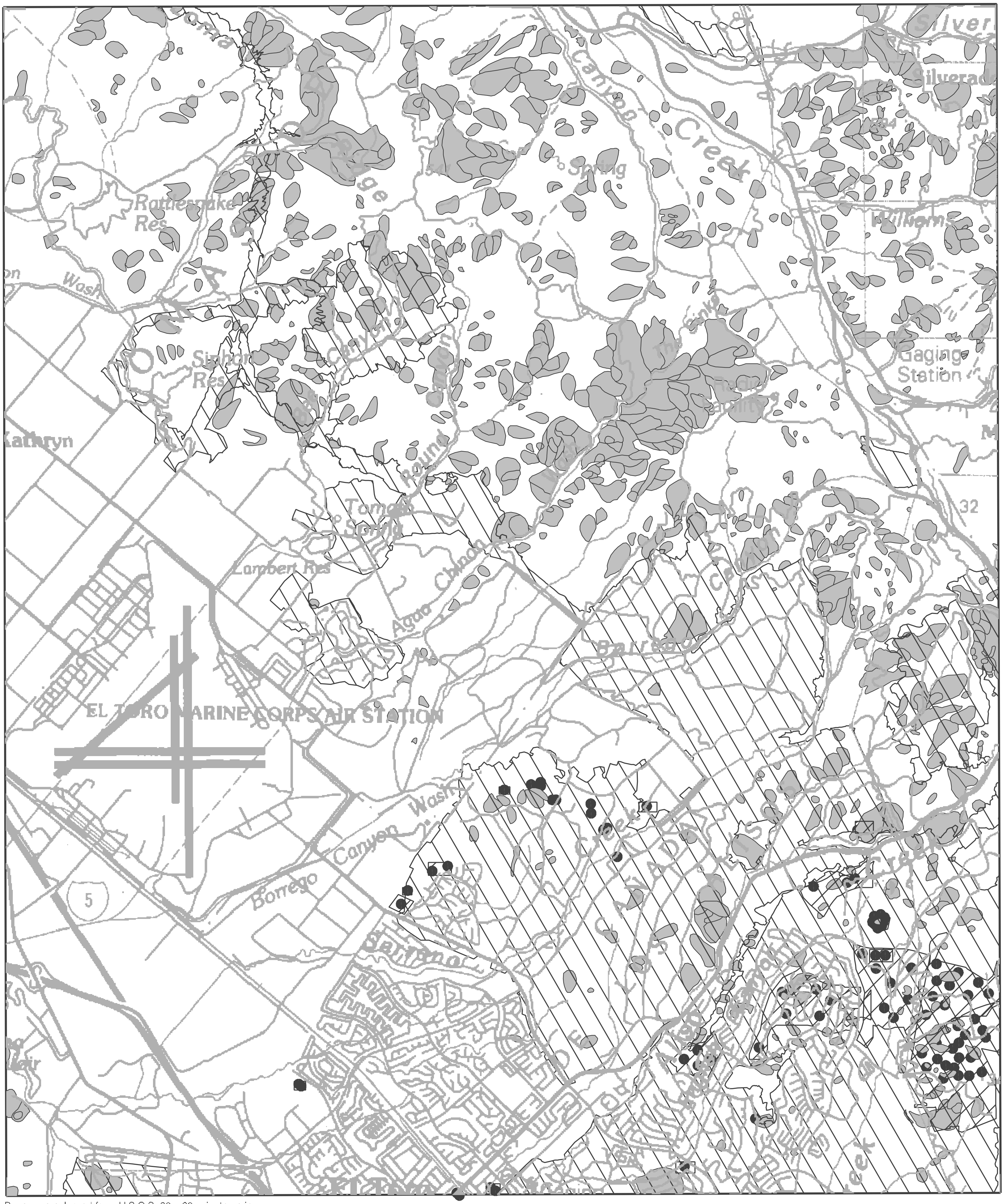
Plate 1.2 Anticipated high ground water levels in the El Toro Quadrangle, Orange County.

● Borehole Site

30 Depth to ground water in feet

ONE MILE

Scale



Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 2.1 Landslide inventory, Shear Test Sample Locations, and Areas of Significant Grading, El Toro Quadrangle.

shear test sample location landslide areas of significant grading tract report with multiple borings

ONE MILE

SCALE